Catena 166 (2018) 220–228

Contents lists available at ScienceDirect

Catena

journal homepage: www.elsevier.com/locate/catena

Changes in selected physical water quality characteristics after thinning in a forested watershed

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ARTICLE INFO

Keywords:
Forestry activities
Thinning
Selective cutting
Streamwater quality
Stream and air temperatures

ABSTRACT

Climate change is a natural phenomenon with far-reaching impacts. Due to global warming, forest vegetation patterns in the Mediterranean region can be affected and the extent of forested areas can be altered. The purpose of this study was to investigate the impact of slightly decreased forest density on physical water quality parameters by employing 18% thinning with a paired watershed methodology in a broadleaf forest ecosystem. After a 70-month monitoring period that started in December 2005, calibration equations were established between control and treatment watersheds for streamwater parameters including pH, color, turbidity, electrical conductivity (EC), suspended sediment concentration (SSC), water and air temperatures. After 18% standing timber volume was harvested from the treatment watershed, streamwater was also sampled for the same parameters in both watersheds during the 46-month treatment period between January 2012 and October 2015. Changes in the mean monthly values of streamwater parameters were determined as the differences between measured and estimated values derived from the calibration equations. Results showed that 18% forest thinning caused 7.3 $\mu S\,cm^{-1}$ increase in the overall average monthly EC, 2.8 NTU in turbidity, 15.1 $mg\,L^{-1}$ in SSC, 0.3 °C increase in the air temperature, and 1.2 °C in the maximum air temperature, whereas it caused 0.5 °C decrease in overall average monthly minimum temperature and 1.3C.P·U in overall mean monthly color. In contrast, forest harvest did not have significant impact on overall average monthly pH and streamwater temperature values. Results of 18% forest harvest indicated that even a small decrease in the forest cover can significantly affect selected physical water quality parameters and hence aquatic life in the forested watersheds.

1. Introduction

Forest ecosystems provide many benefits and services for human well-being, such as providing wood, clean air, recreation, nutrient cycling, preventing disturbance (flood and erosion) damage, and resilience to climate change (Amacher et al., 2014; Hanson et al., 2011; MEA, 2003, 2005; WRI, 2002). Due to soil characteristics, root systems, canopy cover, tree species and forest floor, forest ecosystems have been highlighted as the main contributors of water quality (Eisalou et al., 2013; Fiquepon et al., 2013; Makuch, 2008; Neary et al., 2009; Sun et al., 2004). Besides this vital role of forest ecosystems, forestry activities such as forest thinning, timber harvesting, site preparation and road construction are necessary in order to meet increasing public demand for forest resources. Forestry activities can cause decreases in the forest covered areas. The interactions between forestry activities and forest ecosystems becomes significant because they impact water quality and quantity in the watersheds. Much research has found that forestry management practices have different impacts on hydrologic processes, such as shortening the time of concentration, causing sedimentation, changing streamflow regimes and hence water yield and quality (Arvidson, 2006; Gökbulak et al., 2008; Grace III et al., 2006; Serengil et al., 2007b). These impacts mainly can be attributed to the decrease and alteration of forest cover that affect forest soil and the amount of precipitation reaching the soil surface. On the other hand, the impacts of forestry activities depend on intensity of forestry practices. For example, some research has found that the minimum amount of timber harvest should be at least 20% of the forest cover in order to detect a change in streamflow (Bosch and Hewlett, 1982). In order to examine the effect of timber harvest on watershed hydrology, the paired watershed approach is commonly used worldwide (Binkley and Brown, 1993; Brown et al., 2005; Gökbulak et al., 2016; Neary, 2016; Stednick, 1996). The main goals of paired watershed approach are to examine the effects of forestry activities on watershed hydrology in small scale watersheds and provide management options for large scale watersheds. A number of studies carried out worldwide focused on the relationship between forest harvest and water yield. These studies

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https://doi.org/10.1016/j.catena.2018.04.010
Received 3 November 2017; Received in revised form 2 April 2018; Accepted 6 April 2018
Available online 13 April 2018
0341-8162/

found that water yield generally increases after intensive timber harvest, such as clearcutting. On the other hand, increases in the water yield after timber removal can deteriorate water quality (Gökbulak et al., 2017; NRC, 2008). Although Neary (2016) mentioned that many paired watershed research projects were expanded to investigate the effects of forestry activities on the chemical water quality parameters and nutrient cycling, as in Hornbeck et al. (1997), Bäumler and Zech (1999), Grace III et al. (2006), and Serengil et al. (2007a), studies that examined the effects of timber harvest on physical water quality parameters including pH, electrical conductivity, color, and turbidity have been limited compared to the studies of stream chemistry and water yield. In fact, physical water quality parameters are important water characteristics because the changes in these parameters can indicate the impacts of forestry activities on water quality and hence aquatic life in an easy and practical way compared to other chemical water characteristics. Therefore, physical water quality characteristics can be used as an indicator for recovery of disturbed forested watersheds. In other words, some undesirable characteristics of water can be seen or understood by monitoring some water characteristics such as color, turbidity, stream water temperature, and suspended sediment concentration. Also, some parameters like turbidity and total suspended sediment concentration are interrelated (Davies-Colley and Smith, 2001) and can be considered as an indicator of each other (Bilotta and Brazier, 2008). In this case, high suspended sediment concentration or high turbidity values can be considered as an indication of degradation in potable water quality (Binkley and Brown, 1993). Likewise, EC is also an important physical water quality parameter (Miller et al., 1988) investigated in some paired watershed studies (Ensign and Mallin, 2001; Gökbulak et al., 2008) because it indicates pollution of streamwater with a sudden alteration of vegetation cover (Fondriest Environmental Inc., 2014). Various land use types have significantly different effects on the EC in the streamwater (Bowden et al., 2015; Brauman et al., 2007; Haidary et al., 2013; Serengil, 2003; Tong and Chen, 2002). In general, agriculture and urban areas are the most effective land use types that increase EC in streamwater compared to the other land use types. For instance, Haidary et al. (2013) found a significantly positive relationship between EC and intensity of urban areas but negative relationship for the intensity of forest areas. Similiarly, Bowden et al. (2015) found a higher EC value (1216 $\mu S\ cm^{-1}$) and pH value (9.9) in agricultural and urban areas, respectively. Due to forestry management activities such as thinning, harvesting or clearcuttig, water quality parameters may show different variation depending on the intensity of tree removal, climatic conditions and watershed characteristics (Bäumler and Zech, 1999; Gökbulak et al., 2008; Reuss et al., 1997; Wang et al., 2006). Moreover, forest management activities can also alter the air and streamwater temperatures in the watersheds. Air and streamwater temperatures are important climatic parameters and play a vital role in biological, hydrological and chemical processes in water and soil (Johson and Jones, 2000). In general, removal of forest canopy mostly causes changes in the maximum and minimum air temperatures by influencing the intensity of light distribution, solar radiation, amount of rainfall reaching the soil surface, humidity and wind velocity and therefore, microclimatic conditions in the forested watersheds (Aussenac, 2000). Despite much research into the hydrologic consequences of forestry management activities worldwide, there is a need for more studies conducted under different ecological conditions to understand fully the interactions between water quality and forestry management activities and to determine a threshold level for water quality. This issue is important due to clean water scarcity around the world that results from population increase, land degradation and rapid urbanization, all of which are occurring in Turkey as well. On the other hand, global warming is a real and ongoing phenomenon and the Mediterranean region, including Turkey, is among the most vulnarable regions in the world (Giorgi, 2006; IPCC, 2007; Solomou et al., 2017). Due to global warming, forest cover is expected to shrink or be replaced with herbaceous vegetation cover around the world (Howard, 2012; Hufnagel and Garamvölgyi, 2014; Zeydanlı et al., 2010). The impact of forest cover reduction or vegetation cover change is not well documented in the Mediterranean region. Therefore, the objective of this study was to determine how physical water quality parameters change due to a decrease in forest cover resulting from management activities. In order to investigate the impact of this decrease in forest cover on physical water quality characteristics including pH, electrical conductivity, color, turbidity, suspended sediment concentration, streamwater and air temperatures, 18% of standing timber volume was harvested and the effects on physical water quality parameters were examined by using a paired watershed methodology. Results of this study may help decision makers and forest managers to make projections about the influence of a decrease in the tree density in the context of water quality in the fresh water producing forested watersheds.

2. Material and methods

2.1. Study site

This study was conducted in Belgrad Forest, which is the home of 7 reservoirs providing freshwater to Istanbul (41° 13′ 00″ - 41° 14′ 13″ N, 28° 54′ 53″ - 28° 56′ 37″ E). The two experimental watersheds, W-I (control) and W-IV (treatment), were 1400 m apart (Fig. 1) and a paired watershed methodology, which requires at least two watersheds, was used to investigate the effects of the treatment in the study. The selected watersheds are part of a long-term experimental watershed research project initiated in 1978 to determine the principles of forest management in the fresh water producing watersheds in Istanbul (Balcı et al., 1986). To date, these experimental watersheds have been studied in other research of the relationship between sylvicultural treatments and streamflow and nutrient flow (Gökbulak et al., 2008, 2016; Özyuvaci et al., 2004; Serengil et al., 2007a, 2007b) (Table 1).

The watersheds have similar ecological conditions such as climate, soil, vegetation and topography. According to the Tornthwaite classification method, the watersheds have a humid, mesothermal and oceanic climate with moderate water deficit in the summer months (Özyuvacı, 1999). Average annual precipitation is about 1129 mm and mostly falls in the winter months. Mean annual temperature is about 12.3 °C and varies from 4.2 °C in February to 21.7 °C in August (Özhan et al., 2008). The parent materials in the experimental watersheds are the carboniferous clay schists, neogene loamy and gravelly deposits. Moderately deep to deep soils have high erodibility potential with loamy clay texture and medium to high permeability rates. The forest ecosystem in the watersheds have a crown closure of about 75–100% and mull type forest floor with an average depth of 5–6 cm (Özhan et al., 2010). Dominant vegetation cover in the study site is forest mainly composed of *Quercus petraea* (Mattuschka) Liebl, *Quercus frainetto* Ten., *Quercus cerris* L., and *Fagus orientalis* Lipsky (Yaltırık, 1966). The experimental watersheds also have similar slope and drainage density values. The treatment watershed (W-IV) has an area of 77.5 ha with an average slope of 14.0% and drainage density of 3.8 $km\ km^{-2}$ while the control watershed (W-I) has an area of 71.9 ha with a mean slope of 10.0% and drainage density of 3.6 $km\ km^{-2}$.

2.2. Methods

Two watersheds were selected as a control (W-I) and treatment (W-IV) and monitored for both streamflow and selected physical water quality characteristics between December 2005 and October 2011 for a calibration period of 6 years. During the calibration period, water grab samples were collected from the streams of both watersheds close to outlets just above the V-notch weirs on a weekly basis and analyzed for pH, electrical conductivity (EC), color, turbidity and suspended sediment concentration (SSC) on the same day of collection. EC and pH were analyzed by using WTW Multiline P4 universal meter, color with Hellige aqua tester, turbidity with Hellige turbidimeter and SSC was

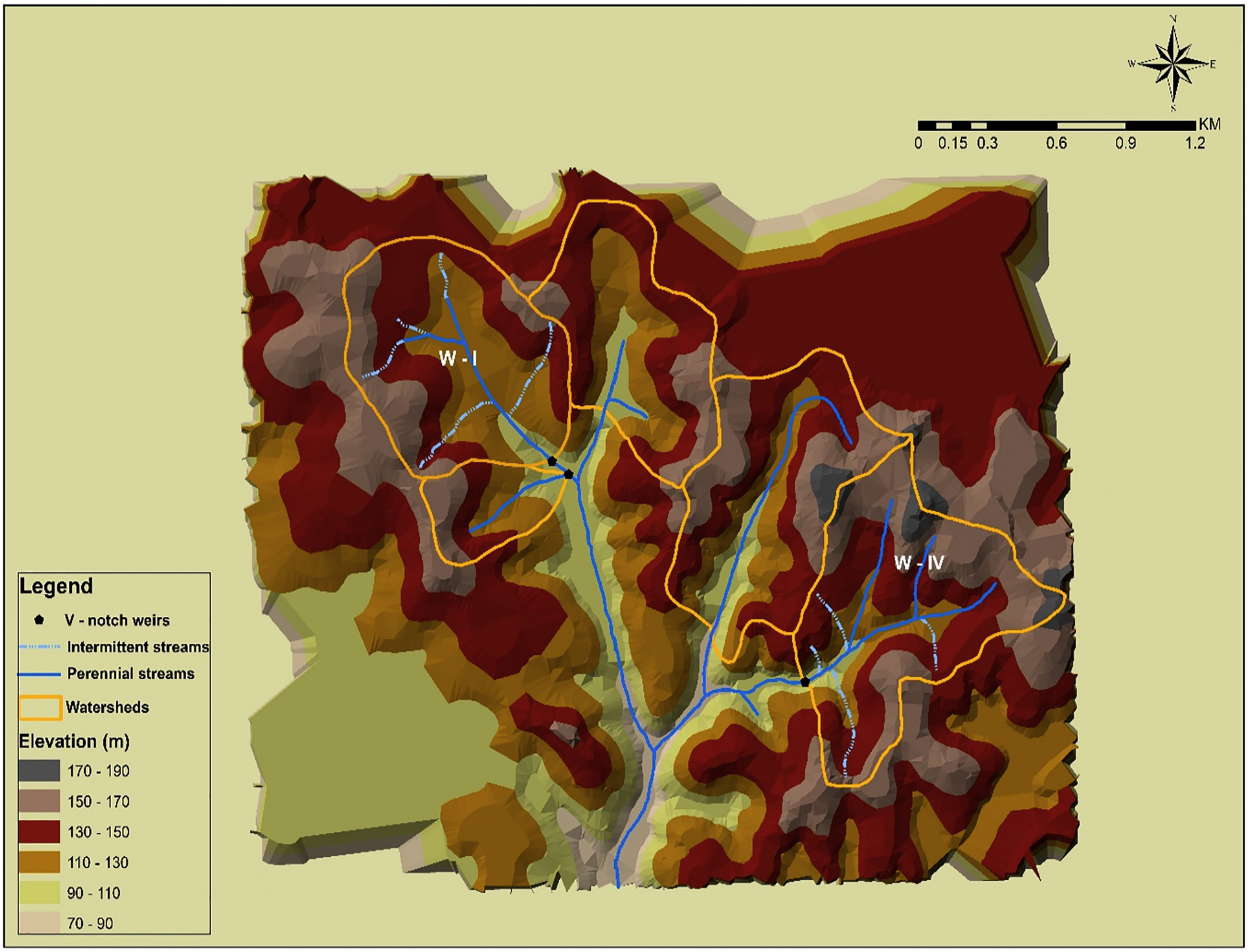

Fig. 1. The location of experimental watersheds (Yurtseven et al., 2017).

determined by evaporation procedure (Balcı et al., 1986). In addition to these selected water quality parameters, streamwater and air temperatures were also recorded every week at the same time for both watersheds. Although maximum and minimum air temperatures were measured on a weekly basis for each month, the highest and lowest values among the weekly measurements were considered as representative of the monthly maximum and minimum air temperatures for a given month. Thinning is a commonly applied practice in Turkish forestry. This study was performed in the same experimental watershed that had been subject to 11% thinning in 1985. Results of this previous research were was published (Gökbulak et al., 2008). By increasing thinning intensity from 11% to 18%, we also try to increase thinning intensity to determine the threshold value for this region, which is located between the sub-humid Southeastern Europe and the arid Middle East. In October 2011, 18% of the standing timber volume was removed from the treatment watershed (W-IV) and the control watershed (W-I) was left untouched. Forest harvest was completed by the end of December 2011. During the harvest, merchantable material was removed from the study site whereas logging residues were left on the site. After timber removal, streamwater sampling in both watersheds were continued for 46 months until November 2015. Weekly data values of each month were converted to average monthly values and then regression equations were developed between control (W-I) and treatment (W-IV) for each physical water quality parameter (Table 2). In the regression

Table 1
History of experimental watersheds in Belgrad Forest.

Year	Event
1976	Experimental watersheds were determined, weirs were constructed, and water level recording systems were installed
1978–1985	Monitoring was started for nutrient outflow and stream discharge to collect data for a calibration period of upcoming experiment investigating effects of timber harvesting on water quality and water yield
1986	11% of the standing timber volume was removed from the treatment watershed
1986–1996	Monitoring the watershed pairs for streamflow and nutrient discharge for the treatment period
1997–2005	Maintenance of the weirs after a flooding damage
2005–2011	New calibration period for another study
September 2011–December 2011	18% of the standing timber volume was removed from the treatment watershed
2012–2016	Monitoring was completed for water yield and stream water

equations, X was the independent variable representing physical water quality parameter of the control watershed while Y was the dependent variable representing the same parameter of the treatment watershed. The effects of timber harvest on selected water quality parameters and streamwater and air temperatures were determined as the differences between the values measured after timber harvest and values estimated by using the simple linear regression equations. Then the differences between measured and estimated parameters were tested by using the two-tailed paired-sample *t*-test at an alpha level of 0.05 (Zar, 1996).

3. Results

Table 2
Regression equations between W-I (control watershed) and W-IV (treatment watershed) for mean monthly values of selected physical water quality parameters, air and stream-water temperatures, maximum and minimum air temperatures during the calibration period.

Parameters	Regression equations	Correlation coefficient (*r*)	Significance of *r*	Average measured values	
				W-I	W-IV
pH	Y = 2.53 + 0.64 * X	*r* = 0.79 (n = 70)	*P* < 0.001	7.5 ± 0.04	7.4 ± 0.03
EC (μS cm^{-1})	Y = 39.35 + 0.60 * X	*r* = 0.89 (n = 70)	*P* < 0.001	338.0 ± 7.4	243.3 ± 5.0
Color (C.P·U)	Y = −2.15 + 0.85 * X	*r* = 0.81 (n = 70)	*P* < 0.001	18 ± 1.2	13.1 ± 1.2
Turbidity (NTU)	Y = 1.79 + 0.45 * X	*r* = 0.70 (n = 67)	*P* < 0.001	16.5 ± 1.3	9.3 ± 0.8
SSC (mg L^{-1})	Y = 41.97 + 0.53 * X	*r* = 0.78 (n = 70)	*P* < 0.001	235.1 ± 6.1	166.2 ± 4.1
Air temperature (°C)	Y = − 0.42 + 1.03 * X	*r* = 0.99 (n = 70)	*P* < 0.001	14.3 ± 0.8	14.3 ± 0.8
Maximum air temperature (°C)	Y = − 2.94 + 1.22 * X	*r* = 0.96 (n = 63)	*P* < 0.001	20.9 ± 0.7	22.4 ± 0.8
Minimum air temperature (°C)	Y = − 0.04 + 0.98 * X	r = 0.99 (n = 63)	*P* < 0.001	6.5 ± 0.9	6.3 ± 0.9
Stream water temperature (°C)	Y = 0.04 + 1.02 * X	r = 0.99 (n = 70)	*P* < 0.001	12.6 ± 0.6	12.8 ± 0.6

In this study, the impact of timber harvest was investigated on a suite of physical water characteristics. The effects of timber harvest on water yield and nutrient outflow were also studied and results have been published previously. The effects of 18% of standing timber harvest on runoff and nutrient discharge can be seen in Gökbulak et al. (2016) and Yurtseven et al. (2017).

Regression equations developed between the treatment and control watersheds showed highly significant relationships between the two watersheds during the calibration period for all selected physical water quality parameters, air and streamwater temperatures, with high correlation coefficients ($P < 0.001$, Table 2) (Fig. 2). In the calibration period, W-I had slightly higher pH, EC, color, turbidity, SSC values and lower maximum air and streamwater temperatures than W-IV (Table 2). Both watersheds had similar air and minimum air temperatures during the calibration period (Table 2).

After the timber harvesting, the overall mean monthly streamwater pH did not show significant change and was 7.3 during the post-treatment period (Table 3). Streamwater pH varied between 7.2 and 7.4 and only showed a significant decrease from 7.4 to 7.3 in the fourth post-treatment year ($P < 0.05$; Table 4). Mean monthly values for both measured and estimated streamwater pH changed between 7.2 and 7.4 during the post-treatment period.

In contrast to pH, forest harvesting significantly affected streamwater EC. Overall mean monthly EC values significantly increased from 237.6 (μS cm^{-1}) to 244.9 (μS cm^{-1}) after the treatment ($P < 0.05$; Table 2). The EC values of the streamwater in W-IV did not show the same trend throughout the post-treatment years. It significantly increased in the first and second post-treatment years ($P < 0.05$) and then returned to pre-harvest levels ($P > 0.05$; Table 4). Except for the third post-treatment year, measured EC values of the streamwater were greater than the estimated values (Table 4).

Overall average monthly color value of streamwater significantly decreased from 10.8 to 9.5 (C.P·U) after 18% forest harvesting in W-IV ($P < 0.05$; Table 3). A significant decrease from 10.8 to 7.5 (C.P·U) occurred in the third post-treatment year whereas tree removal did not affect streamwater color in the first, second and fourth post-treatment years in W-IV (Table 4). Mean monthly measured color values changed between 6.4 (C.P·U) in the fourth post-harvest year and 13.4 (C.P·U) in the second post-harvest year whereas estimated values varied from 7.0 (C.P·U) in the fourth harvest year to 12.7 (C.P·U) in the second post-treatment year (Table 4).

Overall mean monthly streamwater turbidity significantly increased 2.8 (NTU) from 13.1 to 15.9 (NTU) after timber harvesting ($P < 0.05$; Table 3). On the other hand, even though measured turbidity values slightly increased in the first, second, and fourth post-treatment years, the increases were not great enough to be significant ($P > 0.05$; Table 4). During the post-treatment period, measured turbidity values varied between 12.4 and 22.2 NTU while estimated turbidity values changed from 11.3 to 15.8 NTU (Table 4).

Overall mean monthly suspended sediment concentration (SSC) showed significant increase from 186.2 to 201.3 (mg L^{-1}) after 18% tree removal ($P < 0.05$; Table 3) and also significant increases in the SSC concentrations during post-treatment, except for the third post-treatment year. The SSC concentration significantly increased 20.5 mg L^{-1} in the first, 19.3 mg L^{-1} in the second, and 16 mg L^{-1} in the fourth post-treatment years ($P < 0.05$; Table 4). A 5 mg L^{-1} increase occurred in the third post-treatment year but it was not statistically significant.

After the treatment, a significant increase (0.3 °C) was also found in overall mean monthly air temperature ($P < 0.05$; Table 3). During the four post-treatment years, monthly measured air temperatures varied between 14.5 °C and 16.0 °C whereas estimated values changed from 14.4 °C to 15.5 °C (Table 4). However, significant increase in the mean monthly air temperature occurred only following the first year after timber harvest and then returned to pre-harvest levels (Table 4). In our study, overall mean monthly measured and estimated temperatures were 13.1 °C and 13.2 °C, respectively and they were not significantly different (Table 3). Insignificant measured and estimated mean monthly streamwater temperatures followed almost the same trend for the post-harvest period. They were 13.4 °C and 13.1 °C in the first, 12.4 °C and 12.6 °C in the second, 13.0 °C and 13.1 °C in the third, and 13.7 °C and 14.0 °C in the fourth post-treatment years, respectively (Table 4).

In addition to significant increase in the overall mean monthly air temperature, mean maximum and minimum monthly temperatures were also affected by the treatment. Overall mean monthly maximum air temperature significantly increased 1.2 °C from 22.5 °C to 23.7 °C and minimum air temperature significantly decreased 0.5 °C from 6.6 °C to 6.1 °C after timber harvest ($P < 0.05$; Table 3). In another words, variability within the monthly temperatures increased after the treatment (Fowler et al., 1987). Mean monthly measured maximum air temepratures showed changes between 23.1 °C and 24.1 °C whereas estimated temperatures varied from 22.0 °C to 22.8 °C (Table 4). Maximum monthly measured and estimated temperatures were 23.8 °C and 22.6 °C, respectively for the second and 24.1 °C and 22 °C, respectively for the third post-treatment year and there was significant difference between mean monthly measured and estimated maximum

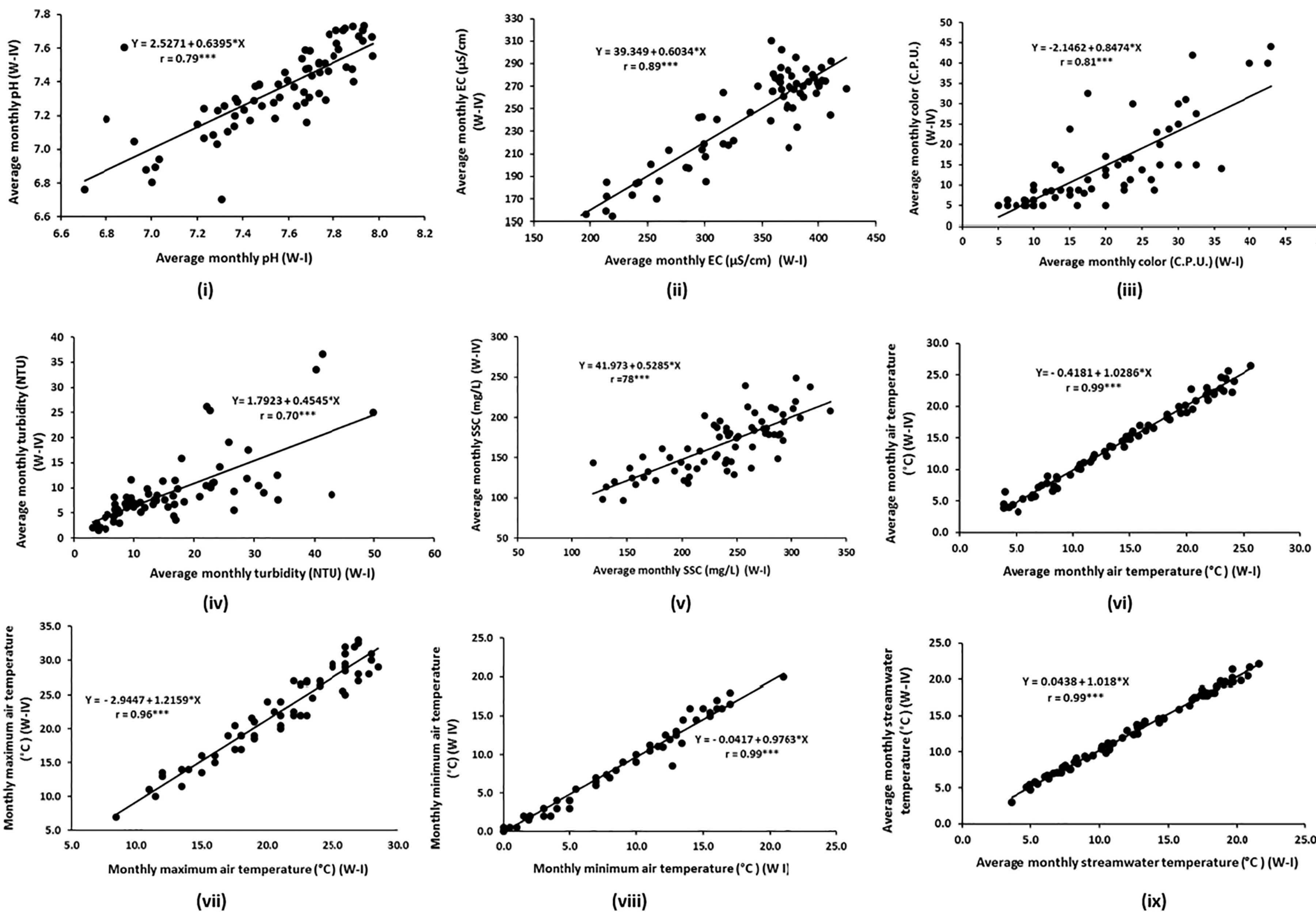

Fig. 2. Relationship between W-I (control watershed) and W-IV (treatment watershed) for i pH, ii EC, iii color, iv turbidity, v SSC of streamwater, vi average monthly air temperature, vii monthly maximum air temperature, viii monthly minimum air temperature, **ix** average monthly streamwater temperature during the calibration period (***Significance at α level of 0.001).

Table 3
Overall average monthly measured and estimated values (mean ± SER) of selected physical water quality parameters and air and water temperatures during the post-treatment period in the treatment watershed.

Parameters	Overall average		Significance
	Measured	Estimated	
pH	7.3 ± 0.03	7.3 ± 0.03	$P > 0.05$
EC (μS cm^{-1})	244.9 ± 6.8	237.6 ± 5.4	$P < 0.05$
Color (C.P.U)	9.5 ± 0.8	10.8 ± 0.8	$P < 0.05$
Turbidity (NTU)	15.9 ± 1.9	13.1 ± 1.1	$P < 0.05$
SSC (mg L^{-1})	201.3 ± 7.2	186.2 ± 5.4	$P < 0.05$
Air temperature (°C)	15.1 ± 0.9	14.8 ± 0.9	$P < 0.05$
Maximum air temperature (°C)	23.7 ± 0.9	22.5 ± 0.9	$P < 0.05$
Minimum air temperature (°C)	6.1 ± 1.1	6.6 ± 1.0	$P < 0.05$
Stream water temperature (°C)	13.1 ± 0.8	13.2 ± 0.8	$P > 0.05$

temperatures during these post-treatment years (Table 4). On the other hand, in contrast to the mean monthly maximum air temperatures, monthly minimum measured air temperatures were always lower than the estimated temperatures regardless of the post-treatment years. A significant decrease was found only between measured (6.3 °C) and estimated (7.1 °C) minimum temperature values in the fourth post-harvest year ($P < 0.05$; Table 4).

4. Discussion

Effects of 18% forest thinning on some physical water characteristics were examined in this study. There were highly significant relationships between the paired watersheds during the calibration period for all physical water quality parameters, air and stream water temperatures with high correlation coefficients ($P < 0.001$, Table 2). These significant relationships between the control and treatment watersheds with high correlation coefficients indicated that paired watershed approach was a right option to test treatment effects in this study. Also, these relationships between watershed pair during the calibration period were consistent with the results of several studies previously conducted at the same experimental watersheds for water yield and nutrient outflux (Balcı et al., 1986; Gökbulak et al., 2008; Gökbulak et al., 2016; Özyuvaci et al., 2004; Serengil et al., 2007a, 2007b; Yurtseven et al., 2017).

In the present study, streamwater pH showed a significant decrease only four years later after the treatment. Significant decreases in streamwater pH after timber harvest were also reported in previous studies with 40% forest harvest (Bäumler and Zech, 1999) and 11% forest harvest (Gökbulak et al., 2008). Forest harvesting can cause a decrease in the streamwater pH because of organic acid release from decomposition of logging residues and HNO_3 production from enhanced nitrification (Feller, 2005). Contrary to streamwater pH, forest harvesting had a significant impact on the streamwater EC. The EC values of the streamwater did not show the same trend throughout the post-treatment years in the treatment watershed. Results of our study about EC value is not consistent with other studies. For instance, Bäumler and Zech (1999) reported lower EC values in the first post-treatment year after 40% forest harvest and Gökbulak et al. (2008) found a significant decrease in overall average monthly EC value in the streamwater of the treatment watershed after 11% forest harvest in the same study site. The differences among the studies can be related to the intensity of timber removal, the span of post-treatment period, climate and watershed characteristics in the study sites. The result of our study for streamwater color also was not consistent with Dallaire (2006) who found that deforestation and logging operations increase color values in the streams as a result of increase in the dissolved organic carbon concentration in the streamwater after harvest. However, similar to our finding, Gökbulak et al. (2008) found a significant decrease in streamwater color after 11% forest harvest in the same region. They suggested that this is because the logging residues left on the ground acted as sponge and increased the water-holding capacity of the forest floor and hence delayed an increase in sudden runoff in the stream and retarded surface flow.

Even though overall mean monthly streamwater turbidity significantly increased after timber harvesting, mean monthly measured and estimated turbidity values were similar throughout the post-treatment years. As expected due to increase in the overall mean monthly suspended sediment concentration after tree removal in W-IV, overall mean monthly stream water turbidity also increased. Results of our study were different from that of other studies. Under low streamflow discharge and slight forest harvesting practices, sediment concentration cannot be changed after timber harvesting. For instance, Gökbulak et al. (2008) found a significant decrease in the streamwater turbidity

Table 4
Mean monthly measured and estimated values (mean ± SER) of selected physical water quality parameters for treatment watershed during the post-treatment period.

Parameters	Post-treatment period							
	2012 (n = 12)		2013 (n = 12)		2014 (n = 12)		2015 (n = 10)	
	Measured	Estimated	Measured	Estimated	Measured	Estimated	Measured	Estimated
pH	7.2 ± 0.1	7.2 ± 0.1	7.4 ± 0.04	7.3 ± 0.1	7.3 ± 0.04	7.3 ± 0.03	7.3 ± 0.1	7.4 ± 0.1
Significance	$P > 0.05$		$P > 0.05$		$P > 0.05$		$P < 0.05$	
EC (μS cm^{-1})	235.9 ± 16.2	225.2 ± 12.4	253.0 ± 12.8	239.4 ± 10.3	248.9 ± 9.6	251.1 ± 6.8	241.2 ± 16.6	234.3 ± 13.6
Significance	$P < 0.05$		$P < 0.05$		$P > 0.05$		$P > 0.05$	
Color (C.P·U)	10.2 ± 1.5	12.2 ± 1.5	13.4 ± 1.9	12.7 ± 1.8	7.5 ± 1.0	10.8 ± 1.5	6.4 ± 1.0	7.0 ± 1.2
Significance	$P > 0.05$		$P > 0.05$		$P < 0.05$		$P > 0.05$	
Turbidity (NTU)	22.2 ± 5.1	15.8 ± 2.6	14.2 ± 1.6	12.6 ± 1.6	12.4 ± 2.5	12.4 ± 1.7	14.1 ± 4.8	11.3 ± 2.4
Significance	$P > 0.05$		$P > 0.05$		$P > 0.05$		$P > 0.05$	
SSC (mg L^{-1})	192.9 ± 11.5	172.4 ± 7.8	195.5 ± 17.7	176.2 ± 11.3	222.7 ± 15.0	217.7 ± 9.6	192.8 ± 11.5	176.8 ± 9.4
Significance	$P < 0.05$		$P < 0.05$		$P > 0.05$		$P < 0.05$	
Air temperature (°C)	15.3 ± 2.3	14.7 ± 2.2	14.5 ± 2.0	14.6 ± 2.0	14.8 ± 1.6	14.4 ± 1.5	16.0 ± 2.0	15.5 ± 2.1
Significance	$P < 0.05$		$P > 0.05$		$P > 0.05$		$P > 0.05$	
Maximum air temperature (°C)	23.1 ± 2.0	22.7 ± 2.1	23.8 ± 1.8	22.6 ± 1.8	24.1 ± 1.6	22.0 ± 1.4	23.7 ± 2.0	22.8 ± 2.0
Significance	$P > 0.05$		$P < 0.05$		$P < 0.05$		$P > 0.05$	
Minimum air temperature (°C)	5.9 ± 2.4	6.4 ± 2.3	5.9 ± 2.4	6.4 ± 2.3	6.8 ± 1.7	7.4 ± 1.5	6.3 ± 2.6	7.1 ± 2.6
Significance	$P > 0.05$		$P > 0.05$		$P > 0.05$		$P < 0.05$	
Streamwater temperature (°C)	13.4 ± 1.8	13.1 ± 1.7	12.4 ± 1.5	12.6 ± 1.4	13.0 ± 1.3	13.1 ± 1.6	13.7 ± 1.8	14.0 ± 1.7
Significance	$P > 0.05$		$P > 0.05$		$P > 0.05$		$P > 0.05$	

after 11% timber removal and they attributed this decrease to low streamflow discharge during the post-treatment period.

Suspended sediment concentration was affected by the forest harvesting as expected in this study and reported in other studies (Binkley and Brown, 1993; Brown et al., 2012; Gökbulak et al., 2008; Grace III et al., 2006; Simonit et al., 2015; Webb et al., 2012). In general, following timber removal, soil surface erosion accelerates in some degree depending on intensity of timber harvest and distruption of soil conditions (Swank et al., 1989) and can cause suspended sediment concentration increase in the streamwater (Binkley and Brown, 1993; Stednick, 2000). Therefore, suspended sediment concentration increases when intensity of forest harvesting is high. In fact, Boggs et al. (2016) found significant increase in suspended sediment loads with the increase in harvest intensity. Similarly, Wynn et al. (2000) reported increases in the suspended sediment concentration after intensive timber harvesting. In contrast, under low harvest intensity, suspended sediment concentration cannot show significant increase as found by Gökbulak et al. (2008) after 11% timber harvest. Results of our study are consistent with results of other studies that show suspended sediment concentration increased after the treatment (Grace III et al., 2006; Webb et al., 2012). However, application of best management practices during the forest harvesting can prevent increases in the suspended sediment concentration in the streamwater (Binkley and Brown, 1993; Boggs et al., 2016).

Due to the treatment, a significant increase occurred in overall mean monthly air temperature and in the average monthly temperature in the first year after the harvest. Since the forest cover plays an important role on microclimatic conditions in forest ecosystems (Aussenac, 2000; Chen et al., 1999; Moore et al., 2005) this result can be related to immediate changes in the microclimatic conditions after timber harvest and then quick recovery of forest canopy following post-treatment years as a result of low timber harvesting intensity. Additionally, since the trees serve as a solar barrier, intensity of solar radiation reaching into forest ecosystem can be lower in a very dense forest cover than in a sparse forest. Under these circumstances, air temperatures can increase after timber harvesting as found in the present study. In fact, Aussenac (2000) investigated the interactions between forest ecosystems and microclimate and mentioned that the climatic characteristics of forest ecosystems can be modified through forestry management activities such as clearing, thinning and clearcutting depending on the intensity of forest cover removal. Even though there is a close relationship between air and streamwater temperatures (Mohseni and Stefan, 1999), the significant increase observed in the air temperature in the treatment watershed after the harvest did not cause any significant change in the streamwater temperature in the post-harvest period in this study. In contrast, Stednick (2000) suggested that streamwater temperature can increase after forest harvest depending on intensity of silvicultural practices. Fowler et al. (1987) found 2 °C increase in the maximum and 2.6 °C decrease in the minimum streamwater temperatures after tree harvesting. A study carried out in the western Cascades, Oregon by Johson and Jones (2000) also showed that clear-cutting caused 7 °C increase in the maximum stream temperature. In our study, overall mean monthly measured and estimated streamwater temperatures were similar. This could be the result of a shading effect by the forest canopy on the stream channel in the treatment watershed since forest cover adjacent to the main stream channel and tributaries was not treated and timber harvest took place farther away from the channels. Webb and Crisp (2006) indicated that shading effect of forest canopy was the major effect influencing exposure of water surface to solar radiation and hence increasing the temperature of forested streams. Insignificant mean monthly measured and estimated mean monthly streamwater temperatures had the same trend throughout the post-harvest period and these results are not consistent with the results of other studies. For instance, Gökbulak et al. (2008) reported significant decreases for both air and streamwater temperatures after 11% forest harvest. Also, results from different studies are not consistent with each other. For example, Johnson (2004) found significant decrease in the maximum streamwater temperature while minimum and mean streamwater temperatures were not affected after the timber harvest in the same study. Bladon et al. (2016) investigated the effect of riparian vegetation on streamwater temperature in the Oregon Coast Range and found that mean daily maximum streamwater temperature did not show any change in the watershed without riparian vegetation after contemporary forest management practices compared to increased daily maximum temperature in the watershed with the riparian vegetation after historical forest harvest practicies. Similarly, Caissie (2006) reviewed the literature and suggested that water temperature variability can occur in the streams due to deforestation as a result of decrease in the canopy coverage. According to the results of these studies and the present research, it can be concluded that one of the major component affecting streamwater temperature is the intensity of forest harvesting in the stream corridors where the shading effect of canopy is changed. In the present study, 18% timber harvest was not intensive enough to change solar radiation intensity reaching stream surface in the treatment watershed and hence influencing streamwater temperature.

In addition to increase in the overall mean monthly air temperature, mean monthly maximum and minimum temperatures were also influenced by the forest thinning. Regardless of the post-treatment years, measured maximum temperatures were always higher than the estimated temperatures but there were significant differences between measured and estimated maximum tempeatures only during the second and third post-harvest years. In contrast to the maximum air temperature, monthly minimum measured air temperatures were always lower than the estimated temperatures during the post-harvest years but a significant difference between measured and estimated values was present only in the fourth post-harvest year. The changes in the maximum and minimum air temperatures can be attributed to the decreased shading effect of canopy cover and hence increased solar radiation and air circulation within the forest ecosystems after forest harvest. Results of this study are consistent with results of previously conducted studies that minimum air temperature decreased and maximum temperature increased after the tree harvest (Fowler et al., 1987; Nakamoto, 1998). Results of this study give some implications about how forest ecosystems may bee affected by climate change, and how a decrease in the density of forest cover, can result in changes in the microclimatic conditions of the forest ecosystems and physical streamwater quality. This means that new forest policy strategies are needed to decrease the impact of climate change, such as obligatory application of best management practices for all forest ecosystems.

5. Conclusion

In this study, we examined the impact of 18% forest harvesting on streamwater pH, color, turbidity, electrical conductivity (EC), suspended sediment concentration (SSC), and water and air temperatures in a subhumid mixed-broadleaved forested watershed. Results showed that 18% timber harvesting changed the majority of physical water quality characteristics except for pH and streamwater temperature despite low harvest intensity. However, the effect of timber harvesting varied for each selected physical water quality parameter. For instance, the overall average of electrical conductivity, color, turbidity, suspended sediment concentration, air and maximum air temperatures were affected significantly while there was not any significant change in the mean monthly pH and streamwater temperature values. Also, significant changes in the EC, SSC, and air temperature occurred in the first and second post-harvest years, after which the changes disappeared for air temperature and EC. Additionally, the results of this study were not consistent with those of several studies conducted under different climatic regions and topographic conditions with different timber harvesting intensities. Therefore, it is hard to make a generilizaiton about effect of light harvesting on physical water quality parameters. However, the results of this study provide information

about the effect of a decrease in forest cover on some water quality parameters. By monitoring physical water quality parameters in the streamwater, decision makers and foresters can use them as an indicator to notice even small and slow changes occurring through time in the forest ecosystems due to human interference or climate change. Therefore, forest managers and decision makers can also utilize results of this study to be aware of effect of their forestry activities on streamwater quality and hence aquatic life in the streams. In conclusion, it can be said that despite low harvesting intensity, timber harvesting affected a majority of water quality parameters in this study. On the other hand, Mediterranean region is one of the most vulnerable area to climate change and a decrease in the forest cover due to climate change is expected. Therefore, changes in the streamwater quality can be expected in the future in the fresh water producing watersheds of the Mediterranean region and necessary measures should be taken and new forest management policies should be established especially for the water poor regions.

Acknowledgements

Authors thank Dr. A. Nihat Balcı, Dr. Necdet Özyuvacı, Dr. Süleyman Özhan, Dr. Kamil Şengönül for setting up Ortadere Watershed Research Station, Chemist Ümit Kılıç for the chemical analyses of the water samples. Authors also appreciated great help of Dr. Pete Gomben from USDA Forest Service, Uinta-Wasatch-Cache National Forest for initinal review of the paper and other anonymous reviewers for their valuable comments in the review process of the paper. This study was partly supported by TUBI·TAK (The Scientific and Technological Research Council of Turkey) with a grant number of TOVAG-105 0 182 between 2006 and 2008 and by Scientific Research Projects Unit of Istanbul University with a grant number of BAP 28027 between 2012 and 2015.

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(Unpublished Research Project Report (Supported by the Scientific and Technological Research Council of Turkey (TUBITAK) with a Grant Number of TOVAG - 105 0 182)).
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